LABEL-FREE MILLIMETER-WAVE SENSOR FOR INVESTIGATIONS OF BIOLOGICAL MODEL MEMBRANE SYSTEMS

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ABSTRACT

We demonstrate a millimeter-wave sensing method based on a coplanar waveguide for biological membrane studies in an open-volume fluidic arrangement. On-wafer measurements of scattering parameters were performed up to 110 GHz. The sensor shows the ability to distinguish the addition of 20% cholesterol in artificial biological membranes, which is an important component influencing the stability and fluidity of such systems. This is the first stage in the development of a millimeter-wave sensor for biological model membrane studies.

KEYWORDS: mm-wave sensor, dielectric spectroscopy, open-volume sensor, biological membranes

INTRODUCTION

Dielectric impedance spectroscopy is a direct, non-invasive and label-free technique which can probe a target and its local environment. The millimeter-wave frequency region (30-300 GHz) has interesting implications, as it contains information about molecular rotations, dielectric relaxation and hydrogen bond interactions [1]. To this end, we investigated the potential of a millimeter-wave (mm-wave) sensor for life science research, focusing on the possibility of label-free studies of biological model membrane systems, since current detection and analysis methods for membranes rely on chemical modifications. Non-invasive, label-free methods, able to distinguish between different membrane compositions, are of great interest in the studies of cell membranes.

EXPERIMENTAL

The mm-wave sensor was designed for integration with an open-volume fluidic arrangement for easy sample manipulation, which does not require specialized fluid-handling equipment, and can be readily interfaced with auxiliary probes. The sensor was based on a 50 Ω coplanar waveguide (CPW) line [2], simulated in ANSYS HFSS. A lift-off technique was employed to pattern the Ti/Au (10/300 nm) metallization, which was then passivated with silicon dioxide (50 nm). In order to ensure a dry probing area, a barrier of 50 μm was patterned on top of the CPW, employing SU-8 epoxy. Figure 1A is a schematic illustration of the sensor, and Figure 1B is a photograph of the completed setup.

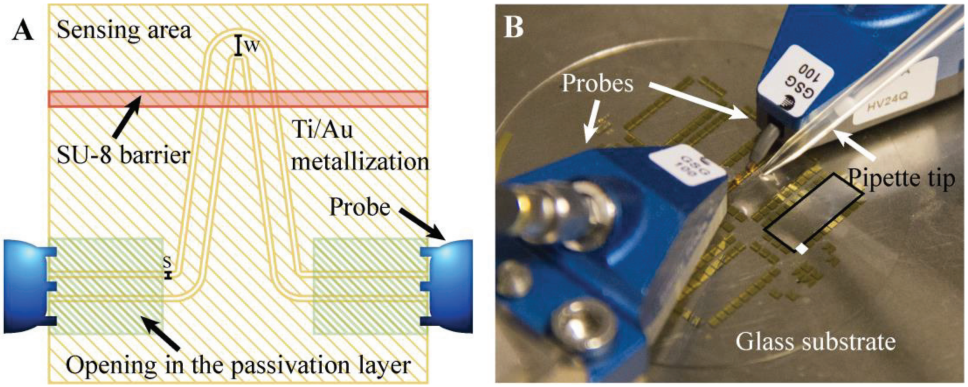

Figure 1 The mm-wave sensor. A) Schematic illustration with the characteristic length scales: w (signal width) and s (signal-to-ground spacer), 50 and 14 μm respectively. B) Photograph of the top-view of the setup. The black frame represents one of the pools formed by the SU-8 barrier and the white square one of the sensors.

Membranes of naturally occurring phospholipids were studied for the characterization of the sensor. Two different membrane compositions were deposited, one without cholesterol and one with a 20% (mass fraction, w/w) cholesterol. Cholesterol was investigated due to its importance and natural occurrence in biological membranes, in addition to its effect on membrane permeability. On-wafer measurements of the scattering parameters were performed up to 110 GHz using an Anritsu Vector Network Analyzer.

RESULTS AND DISCUSSION

Artificial phospholipid membrane with and without cholesterol, was investigated and the experimental results for S_{11} (reflection) and S_{21} (transmission) up to 110 GHz can be seen in Figure 2. Multiple sensors were used, as a means to test the repeatability and accuracy of our measurements. Our findings indicate that the sensor can readily measure the presence of cholesterol in the membrane, detectable as a 0.5 dB loss (Figure 2B). It is a point of note that at 68 GHz, we observed a decrease in both the reflected and the transmitted power, indicating a loss of power in the setup. This occurrence is most likely due to the excitation of substrate modes [3].

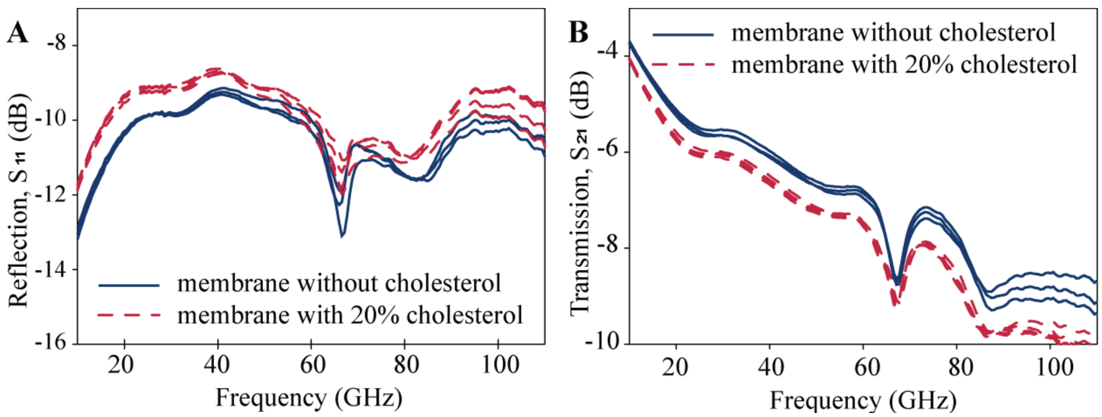

Figure 2 Experimental results A) S_{11} and B) S_{21} versus frequency for a lipid membrane with 20% cholesterol (dashed red lines) and without cholesterol (solid blue lines). The frequency axis begins at 10 GHz.

CONCLUSION

We designed a millimeter-wave sensor based on a CPW line, for determining the composition of model membranes derived from phospholipids. The utility of the device was demonstrated at frequencies up to 110 GHz in an open-volume fluidic arrangement. This is the first step in the development of dielectric spectroscopy sensors for studies of biological and artificial model membrane systems.

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